



OVERVIEW OF BATTERY RECYCLING (NIMH, NI-CD, LI-ION)



Table of Content

Executive Summary.....3

List of Abbreviations.....4

Chapter One

Introduction

1.2 Background.....6

1.3 Scope.....6

1.4 Objective.....6

Chapter Two

Overview of Rechargeable Portable Batteries

2.1 Nickel-metal hydride (NiMH) batteries.....7

2.2 Nickel-Cadmium (Ni-Cd) Batteries.....7

2.3 Lithium-ion batteries.....8

2.4 Battery Recycling.....8

2.5 Battery recycling by location.....9

 2.5.1 North America.....9

 2.5.2 Japan.....9

2.6 Recycling Process.....9

 2.6.1 A Case study of recycling process in Japan.....10

2.7 Health Effects of improper disposal/recycling.....11

 2.7.1 Cadmium.....11

 2.7.2 Nickel.....11

 2.7.3 Cobalt.....11

 2.7.4 Lithium.....12

Chapter Three

Trade and Recycling Cost for Rechargeable Portable Batteries

3.1 Battery Trade.....13

3.2 Global Economic Value of Recycled Materials.....13

3.2.1 Economic Value of Battery Recycling for Non-Battery Producing Countries.....13

3.3 Collection, handling, storage, pre-processing, and shipment13

Chapter Four

Conclusion and Recommendations

4.1 Conclusion.....15

4.2 Recommendation15

References.....17

EXECUTIVE SUMMARY

A battery is a device that converts chemical energy contained within its active materials directly into electric energy by means of an electrochemical oxidation-reduction (redox) reaction. This type of reaction involves the transfer of electrons from one material to another via an electric circuit. Battery can also be defined as an electrochemical device (consisting of one or more electrochemical cells) which can be charged with an electric current and discharged whenever required.

Batteries are broadly classified into two categories, namely primary batteries and secondary batteries. Primary batteries can only be charged once and when they are completely discharged, they become useless and must be discarded. On the other hand, secondary batteries are the batteries that can be charged and reused for many charging-discharging cycles. The electrochemical reactions that take place inside these batteries are usually reversible in nature.

Battery recycling is a recycling activity that recovers materials from used batteries and reusing them in new products. Battery recycling aims to reduce the number of batteries being disposed as municipal solid waste. Batteries contain a number of heavy metals and toxic chemicals like lead, mercury and lithium, and disposing of them by the same process as regular household waste has raised concerns over soil contamination and water pollution. The most common method is thermal treatment, which involves heating the batteries to a high temperature in order to melt the metals. Most types of batteries can be recycled. However, some batteries are recycled more than others, such as lead-acid automotive batteries (nearly 90% are recycled, because of the value and toxicity of their chemicals). Some other batteries like Ni-Cd, Ni-MH, Li-ion can also be recycled, but the recycling rate is nowhere comparable to Lead-acid batteries.

According to the Nigeria Customs Service, Nigeria exported \$10.4 million worth of electrical machinery and equipment in 2021. This included \$1.2 million worth of batteries.

The current recycling rate in Nigeria is low, and there is a need for significant improvements in the collection, transportation, and recycling of batteries. One potential solution to this problem is to export batteries to countries that have well-established recycling infrastructure. Although, there are several challenges that need to be addressed before large-scale battery exports can be implemented. Some of these includes; regulations, transportation costs, environmental concerns, Lack of awareness which could hinder the development of a successful battery export industry.

List of Abbreviations

BAJ – Battery Association of Japan

EPA – Environmental Protection Agency

EPR – Extended Producer Responsibility

EU – European Union

IARC – International Agency for Research on Cancer

JBRC – Japan Battery Recycling Corporation

Li – ion – Lithium ion

NCS – Nigeria Customs Service

Ni – Cd – Nickel Cadmium

NiMH – Nickel Metal Hydride

NTP – National Toxicology Program

PROs – Producer Responsibility Organizations

RBRC – Rechargeable Battery Recycling Corporation

UPS – Uninterruptible Power Supply

UNEP – United Nations Environment Programme

Chapter One

Introduction

1.1 Background

A battery is a device that converts chemical energy contained within its active materials directly into electric energy by means of an electrochemical oxidation-reduction (redox) reaction. This type of reaction involves the transfer of electrons from one material to another via an electric circuit. Battery can also be defined as an electrochemical device (consisting of one or more electrochemical cells) which can be charged with an electric current and discharged whenever required. ⁽¹⁾⁽²⁾

Historically, around the end of the 19th century, batteries were said to provide the primary source of electricity before the development of electric generators and electrical grids. Successive improvements in battery technology facilitated major electrical advances, from early scientific studies to the rise of telegraphs and telephones, eventually leading to portable computers, mobile phones, electric cars, and many other electrical devices.

Batteries are broadly classified into two categories, namely primary batteries and secondary batteries. Primary batteries can only be charged once. When these batteries are completely discharged, they become useless and must be discarded. ⁽³⁾ Example of these batteries are; alkaline battery, mercury battery, silver-oxide battery, solid-state battery, voltaic pile etc. On the other hand, secondary batteries are the batteries that can be charged and reused for many charging-discharging cycles. Secondary batteries are also known as rechargeable batteries. Examples of these batteries are; Aluminum-ion battery, Lithium-ion battery, Nickel-cadmium battery, Nickel–Metal hydride battery, Sodium-ion battery.

1.2 Scope

This study aims to investigate the technical, economic and environmental viability of recycling batteries other than Lead-acid batteries. These includes; NiCd, NiMH, Li-ion. The areas covered but not limited to, include:

1. Recycling by location
2. Recycling process in some countries.
3. Battery trade.
4. Economic value of recycling these batteries
5. Health effects of improper recycling/disposal of battery

1.3 Objectives

1. To evaluate the economic and environmental feasibility of recycling of NiCd, NiMH, Li-ion batteries.
2. To identify potential barriers and opportunities of recycling NiCd, NiMH and Li-ion batteries.

Chapter Two

Overview of Rechargeable Portable Batteries

2.1 Nickel-metal hydride (NiMH) batteries

A **nickel–metal hydride battery (NiMH or Ni–MH)** is a type of rechargeable battery. The chemical reaction at the positive electrode is similar to that of the nickel–cadmium cell (NiCd).⁽⁴⁾ Nickel-metal hydride (NiMH) batteries are used in hybrid automobile batteries, electric razors, toothbrushes, cameras, camcorders, mobile phones, pagers, medical instruments/equipment. These NiMH batteries contain heavy metals like nickel, cobalt, zinc and iron.

NiMH batteries continue to be used in various applications due to their advantages, such as high-power density, low self-discharge rate, and resistance to overcharging. As a result, many countries maintain an interest in the production and use of NiMH batteries, although the market share and production volumes may vary across regions.



Fig 1. NiMH batteries

2.2 Nickel - Cadmium (Ni-Cd) Batteries

Although not as widely used as other conventional batteries—like lead-acid batteries or lithium-ion batteries, nickel-cadmium (NiCd) batteries are a common choice for certain electronic applications that require rechargeable batteries. These batteries consist of nickel oxide hydroxide, metallic cadmium electrodes, and an alkaline (potassium hydroxide) electrolyte solution portable power tools, photography equipment portable electronics, and emergency backup systems. The recycling rates for Ni-Cd batteries vary significantly by region and country. While some countries have implemented effective recycling programs, others still face challenges in improving their recycling rates.⁽⁵⁾



Fig 2. NiCd battery

2.3 Lithium-ion batteries

Lithium-ion batteries are a type of rechargeable battery that use lithium ions as the active material. They are commonly used in portable electronic devices such as laptop computers, mobile phones, and tablets. Lithium-ion batteries are also used in electric vehicles and other applications where high energy density and long cycle life are required. Li-ion batteries have heavy metals like nickel and cobalt as part of their constituents. ⁽⁶⁾

Lithium-ion batteries are used in Portable electronic devices such as laptop computers, mobile phones, and tablets, Electric vehicles and other applications such as medical devices, power tools, and uninterruptible power supplies (UPS).



Fig 5. Li-ion batteries

2.4 Battery Recycling

Battery recycling is a recycling activity that recovers materials from used batteries and reusing them in new products. Battery recycling aims to reduce the number of batteries being disposed as municipal solid waste. Batteries contain a number of heavy metals and toxic chemicals like lead, mercury and lithium, and disposing of them by the same process as regular household waste has raised concerns over soil contamination and water pollution. ⁽⁷⁾

The most common method is thermal treatment, which involves heating the batteries to a high temperature in order to melt the metals. The molten metals are then collected and reused. Other methods of battery recycling include hydrometallurgy, which involves dissolving the batteries in a chemical solution, and pyrometallurgy, which involves burning the batteries.

Battery recycling is important for several reasons. First, it helps to conserve natural resources. By recovering materials from used batteries, we can reduce the need to mine and extract new materials. Second, battery recycling helps to reduce pollution. Batteries contain a variety of hazardous materials (lead,

cadmium etc) that can be released into the environment if they are not properly disposed of. Battery recycling helps to ensure that these materials are safely recycled and reused.

Most types of batteries can be recycled. However, some batteries are recycled more than others, such as lead–acid automotive batteries (nearly 90% are recycled, because of the value and toxicity of their chemicals).⁽⁸⁾ Some other batteries like Ni-Cd, Ni-MH, Li-ion can also be recycled, but the recycling rate is nowhere comparable to Lead-acid batteries.

2.5 Battery recycling by location

2.5.1 North America

The rechargeable battery industry has formed the Rechargeable Battery Recycling Corporation (RBRC), which operates a battery recycling program called Call2Recycle throughout the United States and Canada.^(9, 10) RBRC provides businesses with prepaid shipping containers for rechargeable batteries of all types while consumers can drop off batteries at numerous participating collection centers. It claims that no component of any recycled battery eventually reaches a landfill.

A study estimated battery recycling rates in Canada based on RBRC data.⁽¹¹⁾ In 2002, it wrote, the collection rate was 3.2%. This implies that 3.2% of rechargeable batteries were recycled, and the rest were thrown in the trash. By 2005, it concluded, the collection rate had risen to 5.6%.

In 2009, Kelleher Environmental updated the study. The update estimates the following. "Collection rate values for the 5 [and] 15-year hoarding assumptions respectively are: 8% to 9% for NiCd batteries; 7% to 8% for NiMH batteries; and 45% to 72% for lithium ion and lithium polymer batteries combined."⁽¹²⁾

2.5.2 Japan

Japan does not have a single national battery recycling law, so the advice given is to follow local and regional statutes and codes in disposing batteries. The Battery Association of Japan (BAJ) recommends that alkaline, zinc-carbon, and lithium primary batteries can be disposed of as normal household waste.⁽¹³⁾ The BAJ's stance on button cell and secondary batteries is toward recycling and increasing national standardisation of procedures for dealing with these types of batteries.⁽¹⁴⁾

In April 2004, the Japan Portable Rechargeable Battery Recycling (JBRC) was created to handle and promote battery recycling throughout Japan. They provide battery recycling containers to shops and other collection points.⁽¹⁵⁾

2.6 Recycling Process

Recycling starts by sorting batteries into chemistries. Collection centers place lead acid, nickel-cadmium, nickel-metal-hydride and lithium ion into designated drums, sacks or boxes. Battery recyclers claim that recycling can be made profitable if a steady stream of batteries, sorted by chemistry, is made available.

The recycling process begins by removing the combustible material, such as plastics and insulation, with a gas-fired thermal oxidizer. Polluting particles created by the burning process are eliminated by the plant's scrubber before release into the atmosphere. This leaves the clean and naked cells with metal content.

The cells are then chopped into small pieces and heated until the metal liquefies. Non-metallic substances are burned off, leaving a black slag on top that a slag arm removes. The alloys settle according to weight and are skimmed off like cream from raw milk while still in liquid form. Some recyclers do not separate the metals on site but pour the liquid metals directly into what the industry refers to as pigs, hogs or nuggets. Battery recycling is energy intensive. Reports reveal that it takes 6 to 10 times more energy to reclaim metals from some recycled batteries than from mining. The exception is the lead acid battery, from which lead can be extracted easily and reused without elaborate processes. ⁽¹⁶⁾

New recycling methods are being developed that retrieve the metals by electrolysis, also known as chemical recycling. The process is said to be more cost effective and produces higher yields with less pollutants than traditional smelting.

2.6.1 A Case study of recycling process in Japan

The process of recycling nickel-metal hydride (NiMH) batteries in Japan typically involves the following steps in the table 1 below

Table 1: Steps and techniques of recycling used battery in Japan ⁽¹⁷⁾

STEPS	TECHNIQUES
Collection	Collections are made from waste management facilities, recycling centers, and collection points set up by battery manufacturers or recycling companies
Sorting and pre-treatment	The collected NiMH batteries are sorted and inspected to remove any non-battery components or contaminants. This step may involve manual sorting, automated sorting using specialized equipment, or a combination of both
Discharging and dismantling	The NiMH batteries are discharged to remove any remaining charge, and then they are dismantled to separate the different components, such as the metal casing, plastic components, and the electrode materials
Mechanical processing	The electrode materials, containing valuable metals like nickel, cobalt, and rare earth elements, undergo mechanical processing, which involves shredding, crushing, or grinding the electrode materials into smaller particles or powder form
Separation and purification	Shredded or crushed electrode materials are then subjected to various separation and purification processes to recover the valuable. Physical

	separation techniques like magnetic separation, density separation, or chemical processes like leaching or solvent extraction may be used.
Metal recovery	Separated and purified metal compounds are then processed further to recover the pure metals. This can involve techniques like electrowinning, chemical precipitation, or smelting, depending on the specific metal and the desired form of the recovered product
Recycling and reuse	Recovered metals, such as nickel, cobalt, and rare earth elements, can be recycled and reused in the production of new NiMH batteries, other battery types, or various other applications that require these metals.

2.7 Health Effects of Improper Disposal/Recycling

2.7.1 Cadmium

The symptoms characteristic of Cd poisoning varies, depending on the length of exposure, the type of diet, and the age and health status of those exposed. Cadmium is mainly absorbed during inhalation, partly through the digestive system when particles of dust are swallowed with saliva. ⁽¹⁸⁾

Breathing air with high levels of cadmium over a short period of time is initially like the flu with chills, fever and muscle pain, then later can cause lung damage, shortness of breath, chest pain and cough, which may lead to death in severe cases. Long-term accumulation of cadmium can lead to kidney disease and cause bones to become weaker. ⁽¹⁹⁾

2.7.2 Nickel

Depending on the dose and length of exposure, as an immunotoxin and carcinogen agent, Ni can cause a variety of health effects, such as contact dermatitis, cardiovascular disease, asthma, lung fibrosis, and respiratory tract cancer as nickel has been listed by National Toxicology Program (NTP) and the International Agency for Research on Cancer (IARC) to have sufficient evidence to cause cancer in humans. ⁽²⁰⁾

However, the exposure of human beings mainly concerns oral ingestion through water and food as nickel may be a contaminant in drinking water and/or food. Environmentally, nickel can accumulate in soil, where it can be toxic to plants and other organisms, while overtime it can enter waterways from mining and industrial activities, as well as from leached batteries. ^(21, 22)

2.7.3 Cobalt

Chronic cobalt ingestion is known to cause serious health problems at doses far less than the lethal dose. Cobalt metal is suspected of causing cancer (i.e., possibly carcinogenic, IARC Group 2B) as per the International Agency for Research on Cancer (IARC) Monographs.

It causes respiratory problems when inhaled. It also causes skin problems when touched; after nickel and chromium, cobalt is a major cause of contact dermatitis. ^(23, 24)

2.7.4 Lithium

The effects of lithium is dependent on the level of exposure. Direct contact with lithium or its compounds can cause skin irritation, burns, and eye damage, while inhaling lithium dust or fumes can irritate the respiratory tract. ⁽²⁵⁾

Environmentally, lithium can leach from used batteries and contaminate groundwater and surface water. It can also accumulate in soil, where it can be toxic to plants and other organisms. Potentially, the food chain can be affected when lithium accumulates in aquatic organisms. ⁽²⁶⁾

While lithium-ion batteries offer numerous advantages, it is important to manage lithium responsibly to minimize its potential health and environmental impacts. Recycling, safe disposal, and sustainable battery design are crucial for mitigating these risks.

Chapter Three

Trade and Recycling Cost for Rechargeable Portable Batteries

3.1 Battery Trade

The Nigeria Customs Service (NCS) does not publish specific statistics on batteries. However, the NCS does publish data on the import and export of electrical machinery and equipment with Harmonized System (HS) code 8507, which includes batteries. ⁽²⁷⁾

Nigeria also exported \$10.4 million worth of electrical machinery and equipment in 2021, this included \$1.2 million worth of batteries. The majority of these exports went to Ghana, followed by Niger and Cameroon. These figures suggest that Nigeria is a net importer of batteries. However, it is important to note that the NCS data does not include data on the import and export of used batteries. ⁽²⁷⁾

3.2 Global Economic Value of Recycled Materials

The economic value of recycled Ni-Cd and Ni-MH batteries varies depending on the market prices of these materials. However, it is generally estimated that the value of recycled materials from these batteries is around 50-75% of the cost of new materials. ⁽²⁸⁾

Data from trading economics shows that Nickel, a valuable component of NiMH batteries, has a price of \$19,386 per metric ton. While Other recoverable materials such as; cobalt, zinc, and plastics are valued at \$27,150, \$2,943.50, \$200 per metric ton respectively. ⁽²⁹⁾

3.2.1 Economic Value of Battery Recycling for Non-Battery Producing Countries

Non-battery producing countries can also attain significant economic value from recycling nickel-cadmium (Ni-Cd), nickel-metal hydride (Ni-MH) and lithium-ion batteries. This is because these countries can export the recycled materials to battery-producing countries, which are in high demand for these materials.

The economic value that non-battery producing countries attain from recycling Ni-Cd, Ni-MH and Li-ion batteries depends on a number of factors, including:

- The market prices of nickel, cadmium, lithium, cobalt, and other recycled materials.
- The cost of collecting and recycling batteries.
- The availability of recycling infrastructure.
- The efficiency of the recycling process.

Despite these factors, non-battery producing countries can generally expect to attain a significant economic value from recycling Ni-Cd, Ni-MH batteries and Li-ion. For example, a study by the United Nations Environment Programme (UNEP) found that the global market for recycled nickel-cadmium batteries was worth over \$1 billion in 2018. ⁽³⁰⁾

3.3 Collection, handling, storage, pre-processing, and shipment

The cost of recycling nickel-cadmium (Ni-Cd) batteries through Extended Producer Responsibility (EPR) programs varies. In Nigeria, for example, producers are required to pay levies to cover the costs of EPR operations, collection, and recycling, but the specific fee structure and amounts are not specified. Though

from unofficial findings, the fees may be higher or lower, depending on the specific EPR program and the type and quantity of batteries being recycled.

The exact cost structure associated with collection, handling, storage, and shipment of (processed or unprocessed) Ni-Cd, NiMH and LIBs is currently difficult to assess as full environmentally sound management in the Nigerian context is still a new field and the costs of recycling are changing constantly.

Collection of batteries is associated with costs. Normally collection costs would be covered by the waste generator or through an EPR scheme. In the absence of these, it is possible to work with existing collection networks (formal or informal) which are used to being paid upon delivery of the material.

With regards to shipment, data has it that in 2020, CTL and Hinckley exported 5t of mobile phone batteries from Nigeria to Belgium and indicated that the total project costs for this effort exceeded 70,000 €, which is evident that shipment of untreated batteries has become very difficult or even impossible in the Nigerian context so that additional local pre-processing is required. ⁽³²⁾

In Japan for example, the amount paid on each stage of the recycling of nickel-cadmium batteries varies depending on the specific stage and the company doing the recycling. ⁽³³⁾ However, in general, the following payments are made:

Collection: Collectors are typically paid a small fee for each battery collected. This fee is usually around 10-20 yen per battery.

Transportation: The cost of transporting batteries from collection points to recycling facilities is typically borne by the recycling company.

Disassembly: The cost of disassembling batteries and separating the different components is typically borne by the recycling company.

Recycling: The cost of recycling the different components of batteries is typically borne by the recycling company.

A case study of how the producer responsibility system works in Japan is the Japan Battery Recycling Center (JBRC). The JBRC is a non-profit organization that was established by battery manufacturers to collect and recycle used batteries. Consumers can bring used batteries to JBRC collection points, which are located at retail stores and other public places. The JBRC then collects the used batteries and transports them to recycling facilities.

The cost of collecting and transporting the used batteries is borne by the JBRC. The cost of recycling the used batteries is borne by the battery manufacturers. The recycling of nickel-cadmium batteries in Japan is a complex process that involves multiple stakeholders. However, the producer responsibility system helps to ensure that batteries are recycled in a safe and environmentally sound manner ⁽³³⁾.

Chapter Four

Conclusion and Recommendations

4.1 Conclusion

Batteries contain hazardous materials, such as heavy metals (Nickel, Mercury, arsenic, zinc) and toxic chemicals (Cadmium, Lead), which can harm the environment if disposed of improperly. Recycling can help prevent these materials from entering the environment and polluting soil, water, and air. Batteries also contain valuable materials, such as nickel, cadmium, and lithium, which can be recovered and reused in the production of new batteries, thereby conserving these resources and reducing the need for mining. Recycling batteries can serve as a form of job creation and stimulate the economy. The establishment of recycling facilities and the collection of batteries for recycling can provide employment opportunities and generate revenue for businesses.

However, the current recycling rate in Nigeria is low, and there is a need for significant improvements in the collection, transportation, and recycling of batteries. One potential solution to this problem is to export batteries to countries that have well-established recycling infrastructure. This could help to increase the recycling rate in Nigeria and reduce the environmental and health risks associated with improper battery disposal. Although, there are several challenges that need to be addressed before large-scale battery exports can be implemented. These challenges include:

1. **Regulations:** The Basel Convention, which Nigeria has ratified, regulates the transboundary movement of hazardous waste. This affects the export of batteries for recycling, requiring strict documentation and consent procedures. Exporting batteries to countries with advanced recycling facilities could be economically beneficial and ensure proper treatment. However, it's crucial to ensure this doesn't become a way for developed countries to dump their e-waste in Nigeria. There's a risk of exploitation if proper safeguards aren't in place. Nigeria needs to ensure any export arrangements are fair and don't perpetuate environmental injustice.
2. **Transportation costs:** The transportation of batteries can be expensive, especially for large quantities. This could make it difficult for small businesses and individual consumers to participate in battery export programs.
3. **Environmental concerns:** The transportation of batteries can also pose environmental risks if not done properly. Batteries contain hazardous materials, and if they are not packaged and transported safely, they could leak or explode, causing harm to people and the environment.
4. **Lack of awareness:** Many people in Nigeria are not aware of the importance of recycling batteries or the potential benefits of exporting batteries. This lack of awareness could hinder the development of a successful battery export industry.

4.2 Recommendations

In order to promote the recycling of Ni-Cd, NiMH, and Li-ion batteries in Nigeria, the following recommendations are made:

1. The Manufacturers/Importers through their support in promoting battery recycling can create incentive program for consumers to participate in the take back, while the Producers Responsibility

Organizations (PROs) in collaboration with the states provide receptacles and set up collection points in strategic location like at the retailers, municipalities or at the recycling centers.

2. Consumer education through public awareness campaigns, school programs and community outreach initiatives by the Government in collaboration with the PROs will serve as a strong tool in the Environmentally Sound Management of used batteries and as well as intimate the public on the potential benefits of exporting batteries.
3. Establishment of recycling facilities and the development of efficient recycling processes are essential for the successful recycling of batteries in Nigeria. This requires a Public - private partnership to ensure that batteries are collected and recycled in a safe and environmentally sound manner
4. The PROs should explore partnership with development partners to provide technical support for environmentally sound practices in the waste battery value chain. The development partners can also provide a platform involving international manufacturers to support the take back system by establishing best practices for EPR programs and also to promote international information sharing to harmonize EPR policies and facilitate compliance.

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